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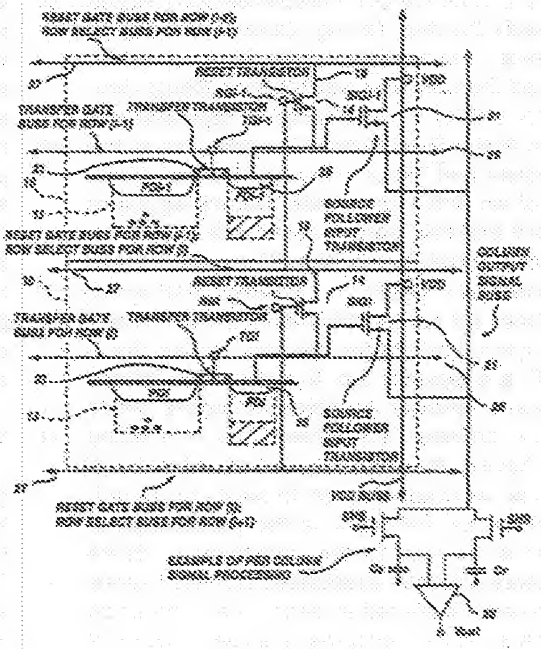
(54) Photodiode active pixel sensor with shared reset signal and row select

(57) An active pixel sensor having a plurality of pixels arranged in rows and columns that are read out of the active pixel sensor in a sequential order of rows with each of the pixels having a photodiode as the photodetecting element. The row that is currently being read has an amplifier within each of the pixel in that row operatively connected to a column signal bus by a reset transistor configuration. A floating diffusion within each pixel is operatively connected to the reset transistor within the pixel such that the reset gate on the reset transistor for the row of photodetectors that is currently being read is also connected to the drain of the next row of pixels to be read resulting in a configuration that allows selection and deselection of rows via the reset busses. During selection of a particular row the amplifiers within each pixel of that row are operatively connected to the column signal bus while the amplifiers of the remaining rows are deselected and not connected to the column signal bus.

Fig.2



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Description

FIELD OF THE INVENTION

[0001] This invention relates to the field of solid state photo-sensors and imagers referred to as Active Pixel Sensors (APS) that have active circuit elements associated with each pixel, and more specifically to Solid State Imagers that employ photodiode type photodetectors 4 transistor pixels and correlated double sampling (CDS).

BACKGROUND OF THE INVENTION

[0002] APS are solid state imagers wherein each pixel contains the typical solid state pixel elements including a photo-sensing means, reset means, a charge to voltage conversion means, and additionally all or part of an amplifier. The photocharge collected within the pixel is converted to a corresponding voltage or current within the pixel as discussed in prior art documents such as "Active Pixel Sensors: Are CCD's Dinosaurs?", SPIE Vol. 1900-06-8194-1133 July 1993, by Eric Fossum. APS devices have been operated in a manner where each line or row of the imager is selected and then read out using a column select signal as discussed by E. Fossum in "Active Pixel Sensors: Are CCD's Dinosaurs?", SPIE Vol. 1900-06-8194-1133 July 1993 and by R. H. Nixon, S. E. Kemeny, C. O. Staller, and E. R. Fossum, in "128 x128 CMOS Photodiode-type Active Pixel Sensor with On-chip Timing, Control and Signal Chain Electronics". Proceedings of the SPIE vol. 2415, Charge-Coupled Devices and Solid-State Optical Sensors V, paper 34 (1995). The selection of rows and columns within an Active Pixel Sensor is analogous to the selection of words and bits in memory devices. Here, the selection of an entire row would be analogous to selecting a word and the reading out of one of the columns of the Active Pixel Sensor would be analogous to selecting or enabling a single bit line within that word. Conventional prior art photodiode devices teach architectures employing 4 transistor designs, where the 4 transistors (4T) are typically the Transfer, Row Select, Reset, and Source Follower Amplifier transistors. While this architecture provides the advantages of yielding APS devices having the capability to easily perform CDS and provide low readout noise, these 4T pixels suffer from low fill factor. Fill factor is the percentage of pixel area that is devoted to the photosensor. Since these 4 transistors and their associated contact regions and signal busses are placed in each pixel, and since contact regions typically consume a large amount of pixel area due to the required overlap and spacings of various layers, the fill factor for the pixel is reduced because of the large area consumed that could otherwise be used for the photodetector. Connection to each of these components to the appropriate timing signal is done by metal busses that traverse the entire row of pixels. These metal busses are optically opaque and can occlude regions of the photodetector in order to fit them into the pixel pitch. This also reduces the fill factor of the pixel. Decreasing the fill factor reduces the sensitivity and saturation signal of the sensor. This adversely affects the photographic speed and dynamic range of the sensor, performance measures that are critical to obtaining good image quality.

[0003] Prior art devices employing 3 transistor (3T) based pixels have a higher fill factor than 4T pixels, but these 3T pixels cannot easily perform CDS. Sensors that perform CDS employing 3 transistor based pixels, typically first read out and store an image frame comprising a reset level for each pixel on the sensor. Next the signal frame is captured and read out. The reset level frame stored in memory must then be subtracted from the signal frame at each pixel to provide a pixel signal level that is referenced to the pixel reset level prior to integration. This requires an extra frame of memory in the imaging system, and an extra step in the digital signal processing chain, thus adversely affecting the speed, size and cost of the system.

[0004] A typical prior art Photodiode APS pixel is shown in Figure 1. The pixel in Fig. 1 is a prior art 4 transistor pixel that comprises: a photodiode (PD), and transfer transistor (TG); floating diffusion (FD); reset transistor with a reset gate (RG); row select transistor with a row select gate, (RSG); a source follower input signal transistor (SIG); a row select signal buss (RSSB); a reset gate signal buss (RGSB), and a transfer gate signal buss (TGSB). 2 adjacent pixels are shown, each containing identical but separate transistors and row control signal busses for RG, TG and RSG. As stated above these 4 transistor pixels provide low readout noise with CDS by inclusion of an extra transistor per pixel. However the area required to implement the 4th transistor reduces the fill factor of the pixel compared to the 3 transistor pixel.

[0005] It should be readily apparent that there remains a need within the art to provide an alternate pixel architecture that has higher fill factor, and the capability to perform CDS without the need to capture and store entire frames of image data.

SUMMARY OF THE INVENTION

[0006] The present invention provides a high fill factor Photodiode Active Pixel Architecture with the capability to perform Correlated Double Sampling, (CDS). The functionality of a 4 transistor pixel is maintained while eliminating the separate row select transistor. This is done by sharing the RG control signals in one row with the row select means of an adjacent row.

ADVANTAGEOUS EFFECT OF THE INVENTION

[0007] The present invention provides a Photodiode Active Pixel sensor with true Correlated Double Sam-

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pling (CDS), using only 3 transistors resulting in a higher fill factor. The advantage gained is high fill factor, and lower temporal noise. No disadvantages are foreseen.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008]

Fig. 1 is a schematic diagram of two adjacent pixels of prior art architecture for a four transistor Photodiode Active Pixel Sensor pixel;
Fig. 2 is a schematic diagram of two adjacent pixels of a new Photodiode pixel architecture for an Active Pixel Sensor;
Fig. 3 is a timing diagram illustrating the operation of the pixels shown in Fig. 2;
Fig. 4 is a top view layout of the pixel shown in Fig. 2.

DETAILED DESCRIPTION

[0009] Fig. 2 is a schematic illustration of the 3 transistor photodiode pixel architecture for an Active Pixel Sensor (APS) as envisioned by the present invention. The preferred embodiment shown in Fig. 2 illustrates the best mode known to inventor. Other physical embodiments are realizable that are obvious variations of the embodiment shown in Fig. 2, as will be discussed further below. The pixels 10 shown in Fig. 2 are single pixels within an array of pixels having numerous rows and columns. The two row adjacent pixels 10 are shown in Fig. 2, to indicate how control the signal lines in one row are used for another purpose in an adjacent row. For the purpose of illustration of timing and operation, Fig. 2 also contains an example of per column analog signal processing used to read out the sensor. The per column signal processing referred to is the correlated double sampling that is performed under control of the Sample and Hold Signal (SHS) and Sample and Hold Reset (SHR) transistors that activate that sampling of the pixel signal voltage by the Signal Capacitor Cs and the pixel reset voltage by Reset Capacitor Cr.

[0010] As seen in Fig. 2, the pixel 10 comprises: a photodiode photodetector 12 (PD); transfer gate (TG) 23; floating diffusion (FD) 26; a reset transistor 14 with a reset gate 15 (RG); a reset drain 18 for the reset transistor 14; a source follower input signal transistor 21 (SIG); a transfer gate signal buss (TGSB) 26; and a reset gate signal buss (RGSB) 27. The row select and the row select signal buss of the prior art pixel shown in Fig. 1 is eliminated, and the row select process is accomplished in a novel manner discussed hereinbelow. As shown in Fig. 2, the reset gate signal buss (RGSB) 27 of any given row, referred to herein as Row_i is connected to the reset drains 18 of the next row in the readout sequence, referred to herein as Row_{i+1}. The transistor, gate, and signal buss components within the 2 pixels have also been annotated with a subscript to indicate the row that they reside in.

[0011] Referring to Fig. 3, which is a timing diagram used to describe the operation of the 3 transistor pixels 10 shown in Figs. 2, the operation of the new pixel architecture for Figs. 2 will be described. It should also be understood that the pixel operation described takes place for an entire row of pixels 10 in the context of the standard per line rolling shutter operation of CMOS active pixel sensor devices. The diagram shows the timing sequence for the readout of 3 rows within the sensor; Row_{i-1}, Row_i and Row_{i+1}. Each of the signals in the timing diagram have been annotated with a subscript indicating the row that they are associated with. It should be understood that the levels in the timing diagram are relative and can be set to be any predetermined signal level to provide optimized sensor performance.

[0012] The timing diagram begins at a point in time indicated as τ_0, where the integration time for Row_{i-1} has elapsed and the readout of Row_{i-1} commences. Row_{i-2} has been deselected, RG_{i-2} and RG_{i-1} are both high at time τ_1 to reset the floating diffusions in Row_{i-1} (FD_{i-1}) to ~VDD, or some other appropriate predetermined potential. The reset potential now turns on the source follower input transistors in Row_{i-1}(SIG_{i-1}), effectively selecting that row for readout of the reset level of the floating diffusion which is sampled and held on Cr by pulsing SHR at time τ_2. The transfer gates for Row_{i-1} (Tg_{i-1}) are pulsed on at time τ_3 to transfer the signal charge from the photodiodes in Row_{i-1} onto the floating diffusions (FD_{i-1}) of Row_{i-1}. The signal levels of the floating diffusions in Row_{i-1} (FD_{i-1}) are still at a level that effectively selects Row_{i-1} for readout and the signal levels of these floating diffusions (FD_{i-1}) of Row_{i-1} are then sampled and held on Cs by pulsing SHS at time τ_4. Each column in Row_{i-1} is then readout differentially through the per column difference amplifier 32 in the period indicated in the timing diagram by "Readout Row_{i-1}" at time τ_5.

[0013] Following the readout of Row_{i-1}, Row_{i-1} is deselected by pulsing RG_{i-1} on while leaving RG_{i-2} low at time τ_6. This sets the voltage of the floating diffusions for Row_{i-1} (FD_{i-1}) to a level that shuts off the source follower transistors for ROW_{i-1} (SIG_{i-1}), effectively disconnecting the source followers for ROW_{i-1} from the output signal column buss, thus deselecting Row_{i-1}. Next Row_i is selected by pulsing on RG_i while RG_{i-1} is held high at time τ_7. It should be noted that the re-pulsing of RG_{i-1} at time τ_7 simply resets the floating diffusions for the previous row that was read (FD_{i-1}) to a low voltage, keeping the source follower signal transistors for that row (SIG_{i-1}) in a non-enabled state, effectively disconnecting the floating diffusions for the row that was previously read (FD_{i-1}) and prevents it from interfering with the output of the current row being read, in this case ROW_i. The reset level of the floating diffusions for ROW_i (Fd_i), are sampled and held by pulsing SHR at time τ_8. TG_i is then

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pulsed "high" to transfer the signal charge from the photodiodes for ROW_i (Pd_i) to the floating diffusions for ROW_i (FD_i) at time τ_{9i}, and the signal level is sampled and held by pulsing SHS at time τ_{10}. Readout of Row_i is then completed similarly to Row_{i-1}.

[0014] This process described for ROW_{i-1} and ROW_i is repeated for Row_{i+1}. Row_i is deselected by setting the FD_i to a low voltage level at τ_{11} by pulsing RG_i "high" while RG_{i-1} is held low disabling the source follower transistor for ROWi. Row_{i+1} is reset, which operates to select Row_{i+1} at time τ_{12} because Rg_i is "high" at that time and Row_{i+1} is effectively selected with all other rows deselected; the reset level is sampled and held at time τ_{13} by activating SHR; the signal level is transferred from PD_{i+1} to FD_{i+1} at time τ_{14} by TG_{i+1}; the signal level is then sampled and held at τ_{15}; and the Row_{i+1} readout occurs at time τ_{16} as previously described.

[0015] This process repeats for all rows of the sensor until the entire frame or sequence of frame readouts is complete. It should be noted that the row select and deselect process could also be combined by eliminating the first of the 2 RG pulses and having enough overlap of the adjacent RG signals as indicated in Fig. 3. The timing illustrated by Fig. 3 is that which the inventor believes that best mode operating the invention.

[0016] From the description of operation provided it is evident that this new 3 transistor photodiode pixel architecture provides true CDS output signal without the need for storing a reset frame.

[0017] The typical prior art Photodiode APS pixel shown in Figure 1 comprised 4 transistors, and 3 row control signal busses. By comparison the new pixel architecture in Fig. 2 comprises only 3 transistors and 2 row control signal busses. The elimination of 1 transistor and buss and the associated contact regions provides more pixel area that can be allocated to the photodetector. This provides substantially higher pixel fill factor and consequently higher optical sensitivity.

[0018] Fig. 4 is a top view of the new pixel architecture as discussed above shown to further illustrate the concept of the present invention. In Fig. 4 the gate of the reset transistor in ROW_{i-1} (RGi-1) is the reset drain for the reset transistor of the next row to be read out in sequence, ROW_i.

[0019] Other aspects of the invention include: the invention wherein the charge to voltage conversion node is a floating diffusion; and the invention wherein the amplifier is a source follower amplifier.

PARTS LIST

[0020]

10	pixel
12	photodiode
14	reset transistor
15	reset gate
18	reset drain
21	source follower input transistor
23	transfer gate
25	floating diffusion
26	transfer gate signal bus
27	row select and photogate signal buss
32	difference amplifier
SHS	sample and hold signal transistor
CS	signal storage capacitor
SHR	sample and hold reset transistor
CR	reset storage capacitor

Claims

1. An active pixel sensor having a plurality of pixels arranged in rows and columns that are read out of the active pixel sensor in a sequential order of rows with at least a plurality of the pixels comprising:

   a photodiode photodetector in the row currently being read that is operatively connected to a charge to voltage conversion node;
   a reset transistor associated with the same pixel as the photodiode photodetector that has a source that is connected to the charge to voltage conversion node;
   a reset gate on the reset transistor connected to a present reset control buss and a drain on the reset transistor connected to a prior reset control buss of the row previously read;
   an amplifier operatively connected to the charge to voltage conversion node.

2. The invention of claim 1 wherein the source of the reset transistor is also the voltage conversion node.

3. The invention of claim 1 wherein application of a first predetermined signal to the prior reset control bus connected to the present reset drain and, and a second predetermined signal to the present reset control buss resets the charge to voltage conversion nodes of the row presently being read.

4. The invention of claim 3 wherein the process of resetting the charge to voltage conversion node also selects the row presently being read.

5. The invention of claim 3 further comprising:

   an output signal column buss for each of the columns that is operatively connected to the amplifiers for photodetectors in that column; and
   the application of the first and second predetermined signals connects the amplifiers of the row currently being read to the output signal column buss.

6. The invention of claim 1 wherein application of a

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first predetermined signal to the prior reset control buss connected to the present reset drain and, and a second predetermined signal to the present reset control buss sets the charge to voltage conversion node to a predetermined potential that disables the amplifiers of the row previously read.

7. The invention of claim 6 wherein the process of disabling the row previously read deselects the row previously read.

8. The invention of claim 6 further comprising:

an output signal column buss for each of the columns that is operatively connected to the amplifiers for photodetectors in that column; and
the application of the first and second predetermined signals disconnects the amplifier of the row previously read from the output signal column buss.

9. A method of forming an active pixel sensor comprising the steps of:

providing a semiconductor substrate having a plurality of pixels ranged in rows and columns such that the rows can be read out sequentially; and
creating at least a portion of the pixels such that there is a present reset buss and a prior reset buss that are associated with at least one designated row within the portion and are operative in a first combination to reset the pixels in the designated row which results in selection of the designated row to be read and operative in a second combination to deselect the pixels in the designated row subsequent to the designated row being read.

10. The method of claim 9 wherein the step of creating further comprises:

creating the portion wherein each of the pixels in the designated row have an amplifier that as a first result of the first combination the amplifier is connected to a column buss; and as a second result of the second combination the pixels in the designated row do not have their amplifiers connected to the column buss.

Fig.1

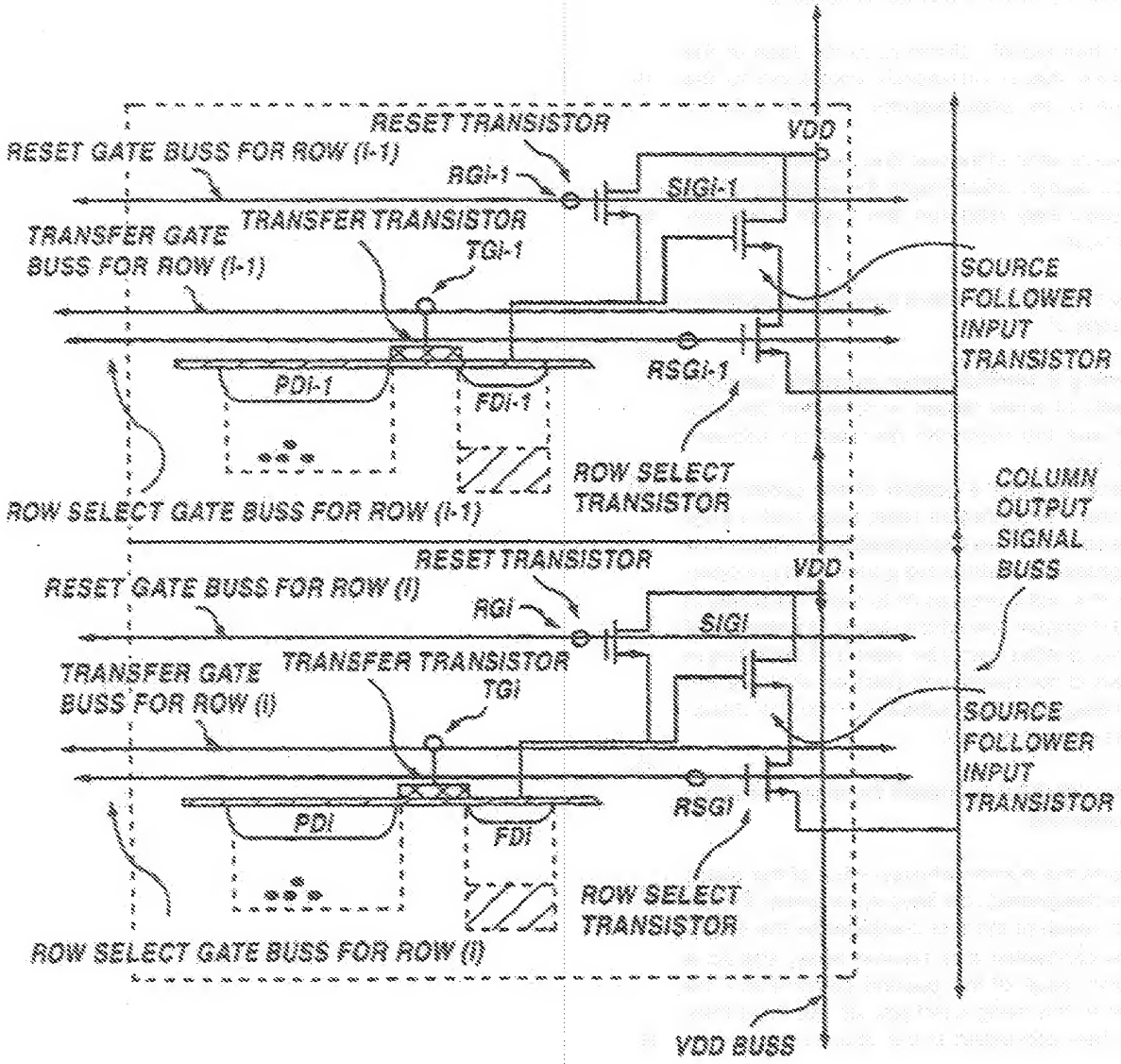

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Fig.2

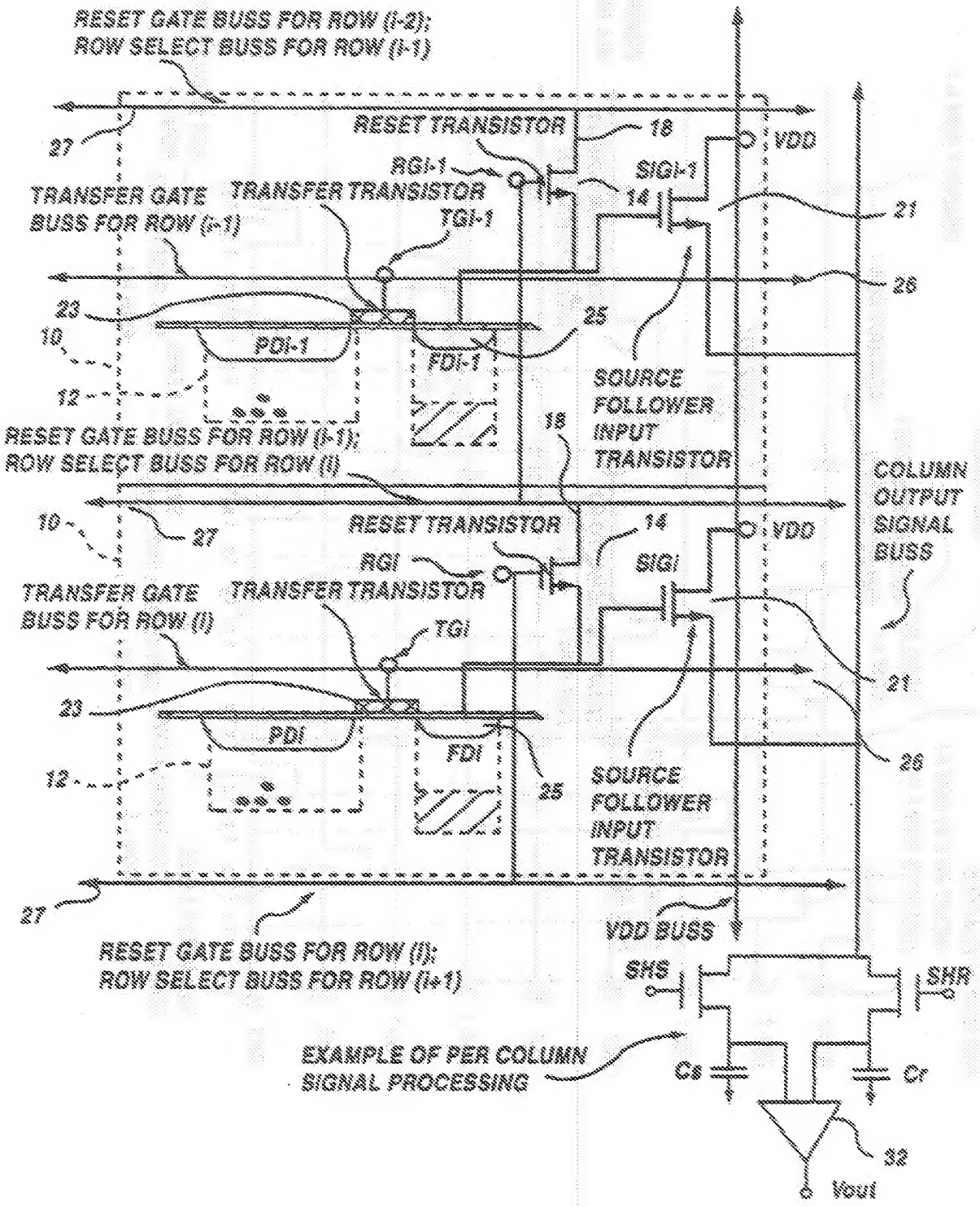
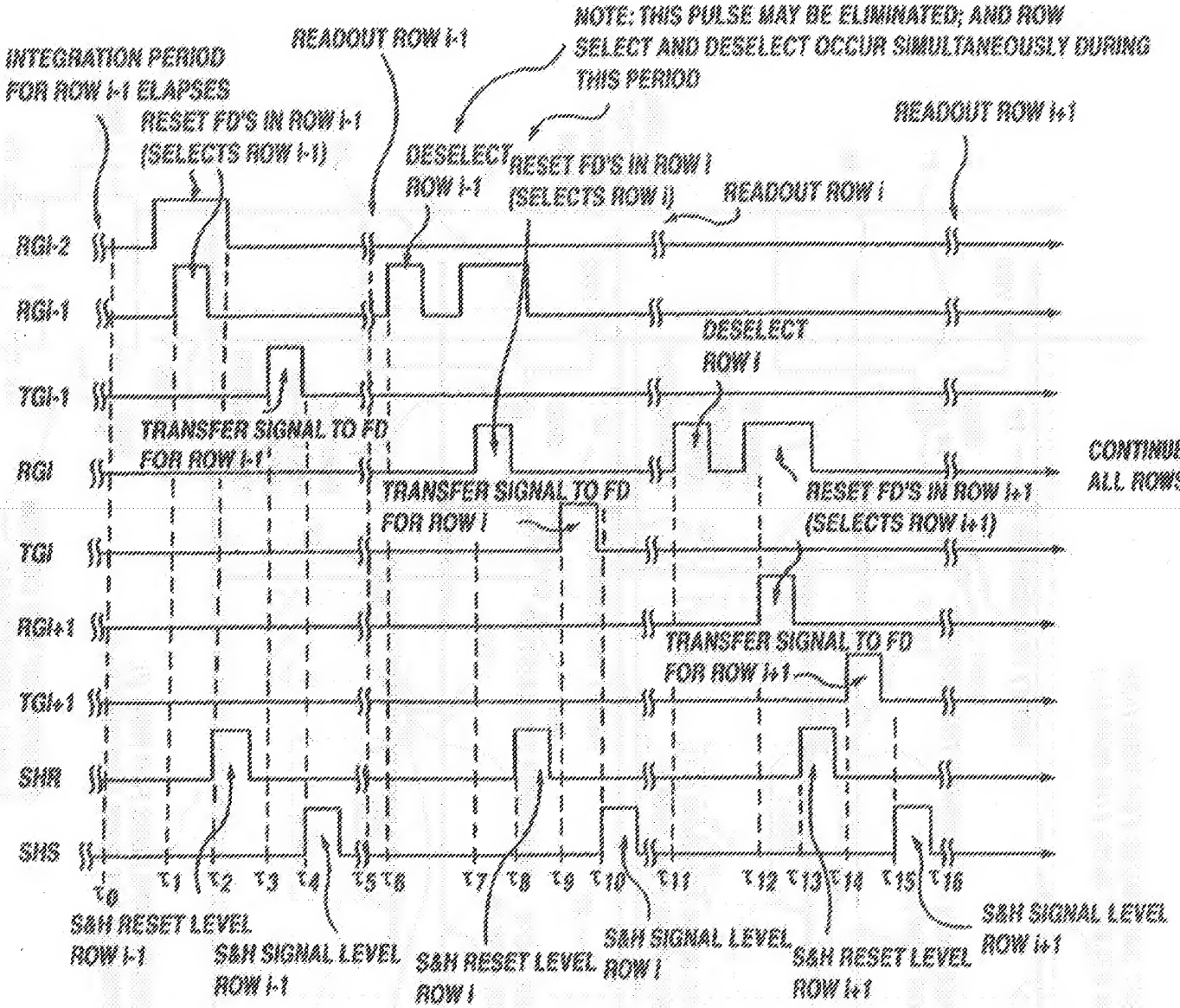
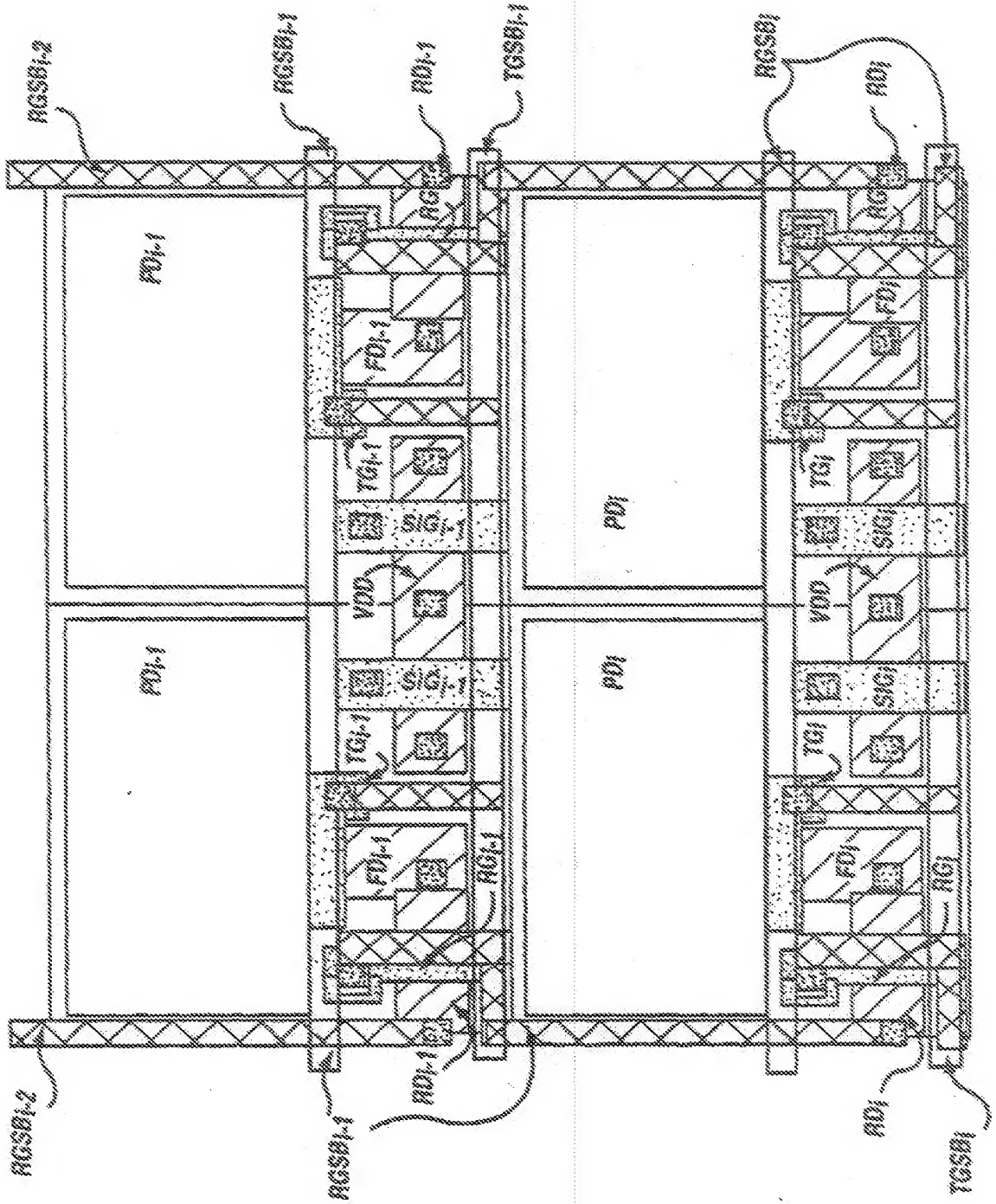

RESET GATE BUSS FOR ROW (i-2);
ROW SELECT BUSS FOR ROW (i-1)
27
RESET TRANSISTOR
18
VDD
RGi-1
SIGi-1
TRANSFER GATE
BUSS FOR ROW (i-1)
TRANSFER TRANSISTOR
TGi-1
14
21
26
23
25
10
PDi-1
FDi-1
12
SOURCE
FOLLOWER
INPUT
TRANSISTOR
RESET GATE BUSS FOR ROW (i-1);
ROW SELECT BUSS FOR ROW (i)
16
COLUMN
OUTPUT
SIGNAL
BUSS
10
27
RESET TRANSISTOR
14
VDD
RGi
SIGi
TRANSFER GATE
BUSS FOR ROW (i)
TRANSFER TRANSISTOR
TGi
21
23
PDi
FDi
26
12
25
SOURCE
FOLLOWER
INPUT
TRANSISTOR
27
VDD BUSS
RESET GATE BUSS FOR ROW (i);
ROW SELECT BUSS FOR ROW (i+1)
SHS
SHR
EXAMPLE OF PER COLUMN
SIGNAL PROCESSING
Cs
Cr
32
Vout

Fig.3


INTEGRATION PERIOD FOR ROW i-1 ELAPSES
RESET FD'S IN ROW i-1 (SELECTS ROW i-1)
READOUT ROW i-1
NOTE: THIS PULSE MAY BE ELIMINATED; AND ROW SELECT AND DESELECT OCCUR SIMULTANEOUSLY DURING THIS PERIOD
DESELECT ROW i-1
RESET FD'S IN ROW i (SELECTS ROW i)
READOUT ROW i
READOUT ROW i+1
RGi-2
RGi-1
TGi-1
RGi
TGi
RGi+1
TGi+1
SHR
SHS
DESELECT ROW i
TRANSFER SIGNAL TO FD FOR ROW i-1
TRANSFER SIGNAL TO FD FOR ROW i
RESET FD'S IN ROW i+1 (SELECTS ROW i+1)
CONTINUES FOR ALL ROWS
TRANSFER SIGNAL TO FD FOR ROW i+1
τ0
τ1
τ2
τ3
τ4
τ5
τ6
τ7
τ8
τ9
τ10
τ11
τ12
τ13
τ14
τ15
τ16
S&H RESET LEVEL ROW i-1
S&H SIGNAL LEVEL ROW i-1
S&H RESET LEVEL ROW i
S&H SIGNAL LEVEL ROW i
S&H RESET LEVEL ROW i+1
S&H SIGNAL LEVEL ROW i+1


RGSB$_{i-2}$
RGSB$_{i-1}$
RD$_{i-1}$
TGSB$_{i-1}$
RGSB$_i$
RD$_i$
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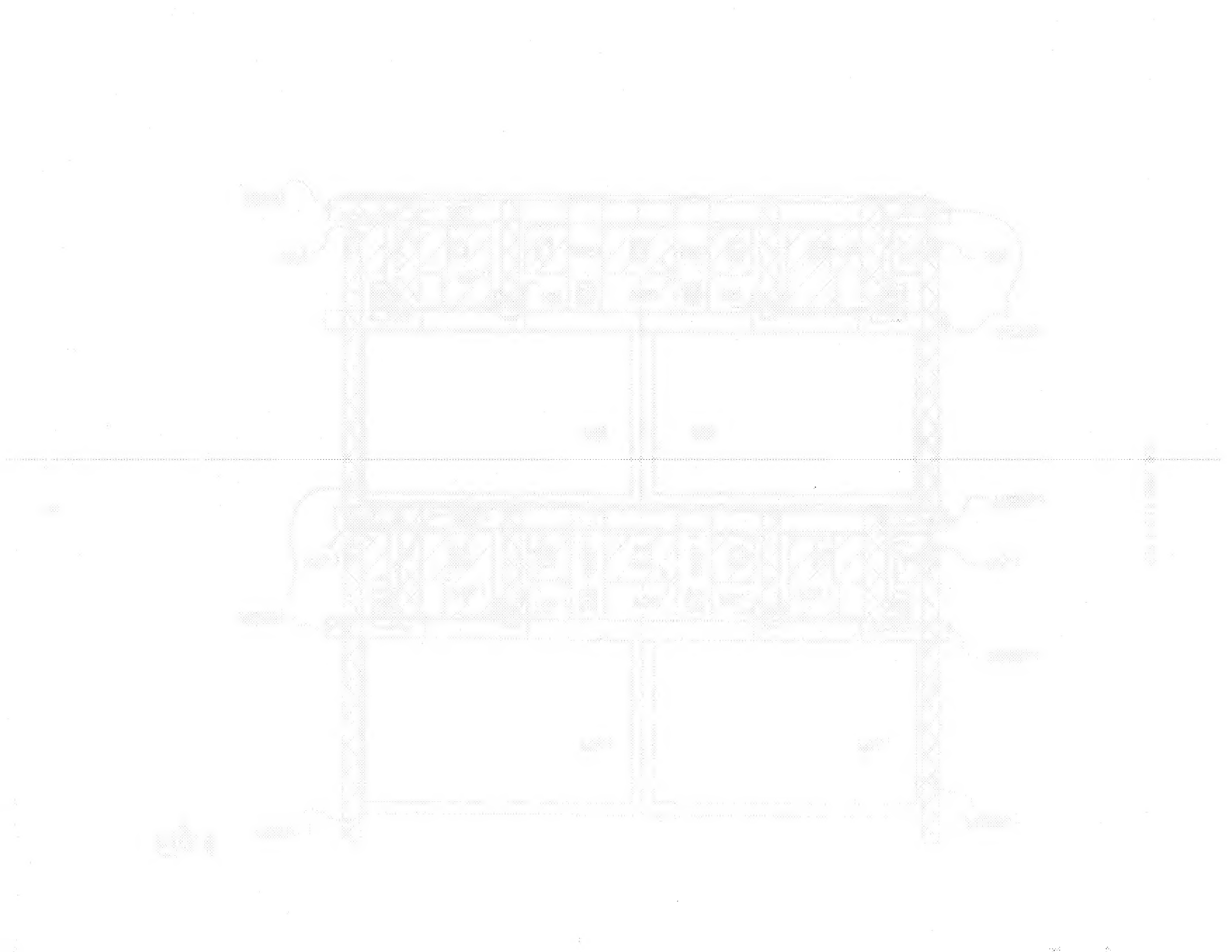
FD$_{i-1}$
FD$_i$
TG$_{i-1}$
TG$_i$
SIG$_{i-1}$
SIG$_i$
VDD
RG$_{i-1}$
RG$_i$
RGSB$_{i-2}$
RGSB$_{i-1}$
RD$_{i-1}$
RD$_i$
TGSB$_i$

Fig.4



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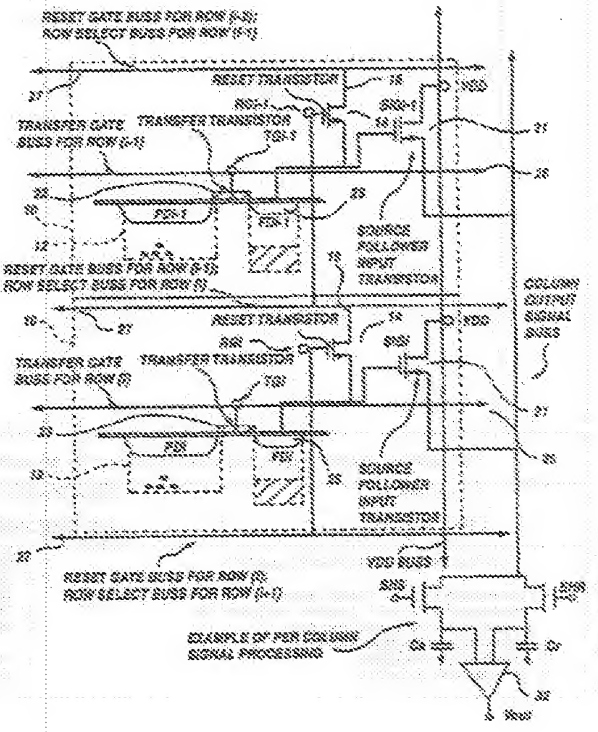
(54) **Photodiode active pixel sensor with shared reset signal and row select**

(57) An active pixel sensor having a plurality of pixels arranged in rows and columns that are read out of the active pixel sensor in a sequential order of rows with each of the pixels having a photodiode as the photodetecting element. The row that is currently being read has an amplifier within each of the pixel in that row operatively connected to a column signal bus by a reset transistor configuration. A floating diffusion within each pixel is operatively connected to the reset transistor within the pixel such that the reset gate on the reset transistor for the row of photodetectors that is currently being read is also connected to the drain of the next row of pixels to be read resulting in a configuration that allows selection and deselection of rows via the reset busses. During selection of a particular row the amplifiers within each pixel of that row are operatively connected to the column signal bus while the amplifiers of the remaining rows are deselected and not connected to the column signal bus.

Fig.2



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EUROPEAN SEARCH REPORT

Application Number
EP 99 20 4059

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.7)
X	EP 0 865 197 A (MATSUSHITA ELECTRONICS CORP) 16 September 1998 (1998-09-16) * figures 4,5 * * column 11, line 13 - column 12, line 51 * ---	9,10	H04N3/15 H01L27/146
A	PATENT ABSTRACTS OF JAPAN vol. 1998, no. 09, 31 July 1998 (1998-07-31) -& JP 10 093070 A (TOSHIBA CORP), 10 April 1998 (1998-04-10) * abstract * ---	1	
A	US 5 539 461 A (ANDOH FUMIHIKO ET AL) 23 July 1996 (1996-07-23) * figure 4 * * column 6, line 1 - column 7, line 14 * ---	1	

TECHNICAL FIELDS SEARCHED (Int.Cl.7)

H01L
H04N

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	16 December 2003	Visscher, E

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
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EPO FORM 1503 03.82 (P04C01)

<INID:DOC> <EP.....1017231A3.(...)>

ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 99 20 4059

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report. The members are as contained in the European Patent Office EDP file on. The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

16-12-2003

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For more details about this annex : see Official Journal of the European Patent Office, No. 12/82

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